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Mechanics, Hydrodynamics and Novel Design of composite marine risers with application on offshore hoses in the Offshore-Renewable industry

AMAECHI CHIEMELA VICTOR

With respect to my:

PhD Degree in Engineering (Offshore-Renewable Structures)
Lancaster University, Engineering Department
***Supervised by:* Prof Jianqiao Ye**

FST 2021 Annual Conference & PhD Event,
@Lancaster University, Faculty of Science & Technology (FST)
#FSTScienceWeek #PhDTalks

Date: Friday, 16/04/2021
Time: 2pm Online via Zoom
Address: Lancaster University, Engineering Department, Bailrigg, Lancaster, UK

PGR Science Week Talks - Saved

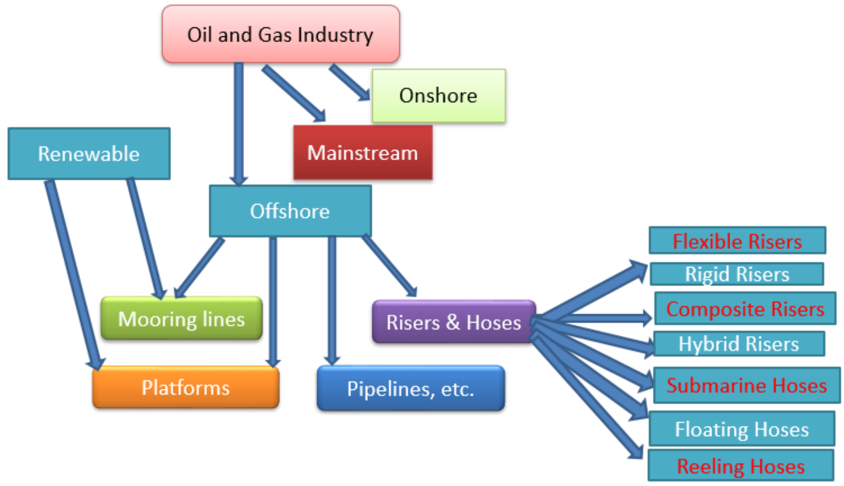
PGR Talks at Science Week, April 2021

Friday April 16th 2pm – 3pm

Session Chair: Debbie Costain

Time	Name	Title	Department
2:05 - 2:10	Mark Ashton	Dual stimuli responsive materials in drug delivery	Chemistry
2:10 - 2:15	Victoria Obatusin	Resource recovery from waste- Optimizing anaerobic digestion to produce clean energy and safe organic fertiliser	LEC
2:15 - 2:20	Rupa Basu	Sub-THz Traveling Wave Tube for Ultra-Capacity Wireless Links	Engineering
2:20 - 2:25	Dhruv Trivedi	Back CO2 the future: the electrochemical reduction of Carbon Dioxide	Chemistry
2:25 - 2:30	Samantha Howlett	Estimating ecosystem functioning provided by parrotfish following a large-scale disturbance in French Polynesia	LEC
2:30 - 2:35	Eduardo Almeida Soares	Towards explainable Deep Neural Networks	SCC
2:35 - 2:40	Joe Roland Adams	Networks physics and cell metabolism in health and Covid-19	Physics
2:40 - 2:45	Victor Chiemela Amaechi	Mechanics, Hydrodynamics and Novel design of composite marine risers with application on offshore hoses in the offshore-renewable industry	Engineering
2:45 - 2:50	Alexander Jung	Navigating the Unikernel Benchmarking and Performance Tuning Labyrinth with ukbench	SCC
2:50 - 2:55	Charlotte Entwistle	TBC	Psychology
2:55 - 3:00	Jonathan Hall	Surpassing Silicon: Transistors Beyond Moore's Law	Physics

Brief on Research



Research Collaborations

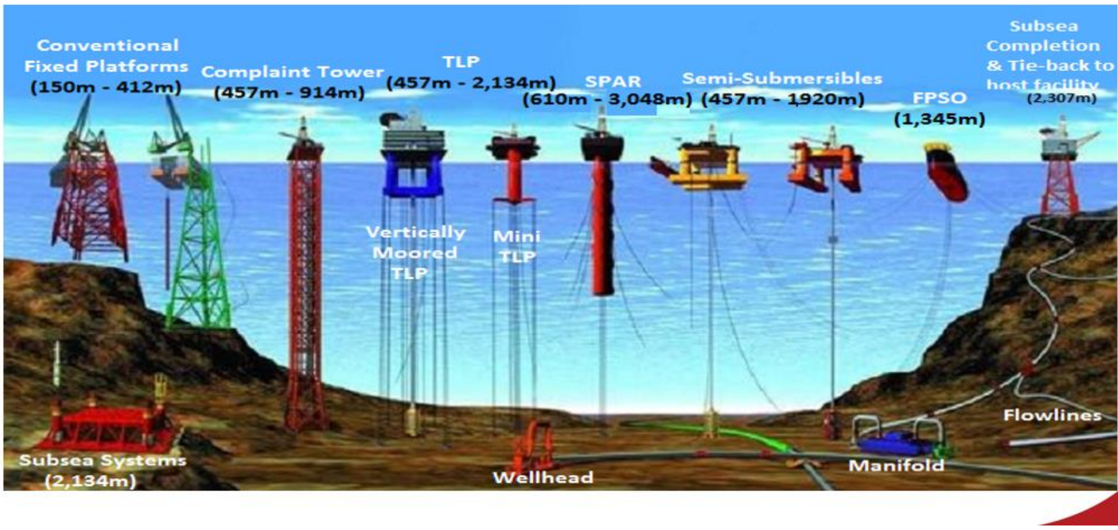
- Tsinghua University, Beijing, China;
- Xidian University, China;
- Orcina, Ulverston, Cumbria;
- Bluewater Netherlands;
- Dunlop Oil and Marine, Grimsby, UK;
- Airborne Oil and Gas Netherlands,
- Magma UK;
- Siemens Ulverston, Cumbria;
- Composites UK;
- Coventry University, Coventry, UK;
- University of Liverpool, Liverpool, UK
- Newcastle University, Newcastle, UK.

ABSTRACT

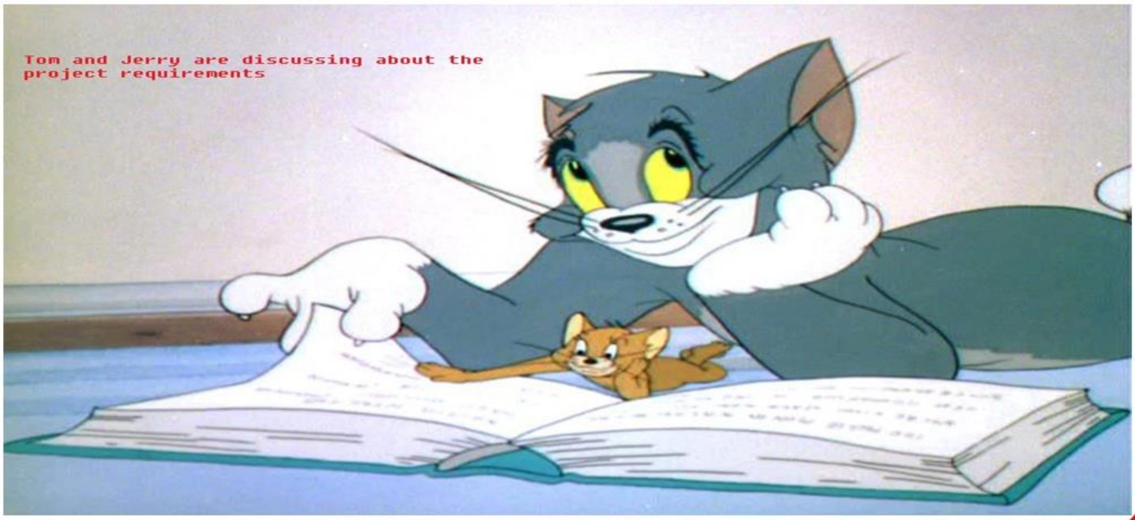
Currently, there are approximately 3,400 deepwater wells in the Gulf of Mexico (GoM) having depths greater than 150 meters, and a worldwide undiscovered deepwater reserves estimated to exceed 200 billion barrels and 25% of the total US reserves (BOEM, 2016), while others are in regions such as Angola, Brazil, Canada, Egypt, India, Morocco and the UK. The application of composite risers in offshore engineering for ultra-deep applications has been facing a lot of challenges, such as in West Africa and Gulf of Mexico. Presently, the steel catenary risers are used for deepwater applications requiring large diameter pipes, while the flexible while top-tensioned risers are used for shallow water applications, but composite riser technology used mostly for deepwaters, as this is an exciting frontier in the offshore industry as it provides a potential solution for future riser design challenges. This research involves hydrodynamic loading using ANSYS AQWA and modelling composite riser using Orcaflex to investigate the Riser Installation behaviour. The behaviour of composite risers is compared against the behaviour of top-tensioned steel risers with the main research focus on the motion characterization and the behaviour as regards the fatigue of composite materials, considering that composite materials are light-weight, combustible but not corrosive. ANSYS APDL and ANSYS ACP are used to model the composite materials and AS4/PEEK was first used considering the mechanical properties make it a good composite material for composite material. Some comparison is made with some research done on composite materials, and further studies is done on the fatigue analysis of the composite risers which is ongoing and specific attention is given on the applicability, and to present the design the local and global analysis, in other to reduce installation and maintenance costs. Recommendations from this will enable other industry specifications like ABS, DNV, API, EN and ISO on composite risers as currently they are limited codes and specifications on composite risers.

What do we get from this Industry?

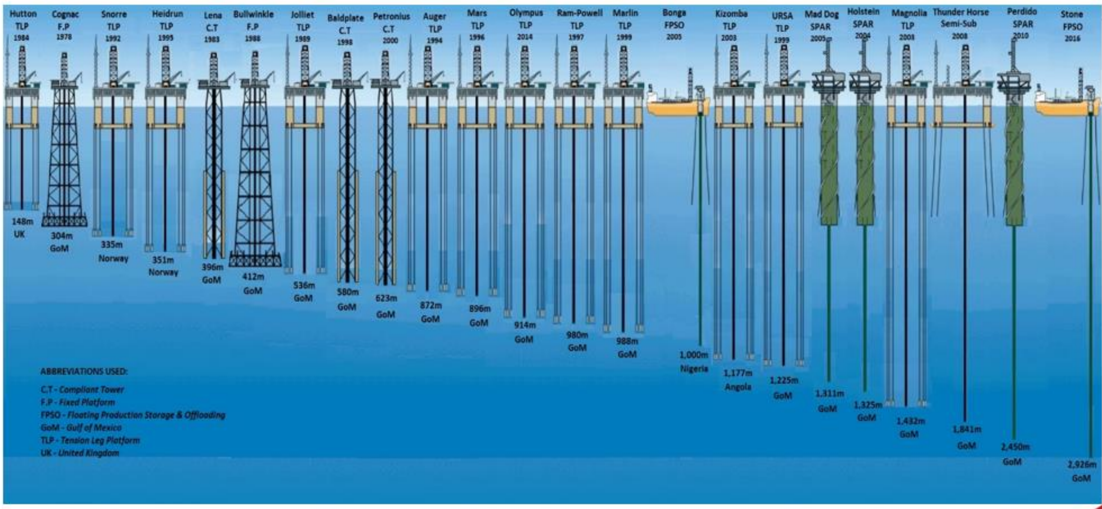
Deepwater systems, platforms& risers (NOAA)



Project Requirements



History of Offshore Deepwaters



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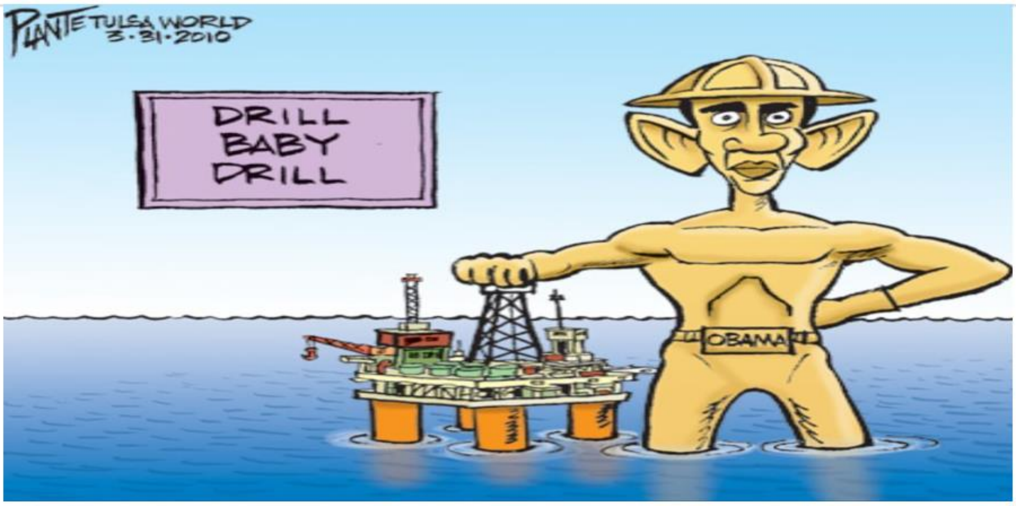
Challenges with Oil and Gas Industry



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Importance of Composite Risers

- Composites are light – High specific strength
- Can be formed into complex shapes
- Very good fatigue resistance claimed
- High corrosion resistance
- Maintenance cost is low
- Comparatively low axial and bending stiffness when compared to steel
- Potential ease of installation (i.e. Reeled pipe)
- Can be designed into desired form

Issues with Composite Risers

- Need more work due to more deep water needs
- Very expensive (high cost of material)
- Limited track record in the offshore industry but it has high applications in other industries
- Design codes, specifications and standards are limited as regards direct applicability to composite risers (recent ones by ABS and DNV have been introduced)
- Hard to inspect sub-laminar damage
- More design models on composite risers are needed on both the composite materials and composite riser structure

Development of Composite Risers / Pipes / Offshore Hoses

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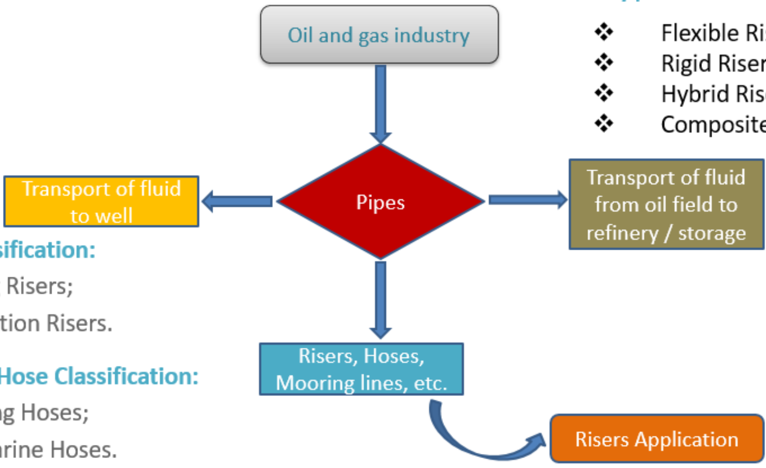
Types of Risers

- ❖ Flexible Risers;
- ❖ Rigid Risers;
- ❖ Hybrid Risers;
- ❖ Composite Risers



- **Riser Classification:**
  - ❑ Drilling Risers;
  - ❑ Production Risers.

- **Offshore Hose Classification:**
  - ❑ Floating Hoses;
  - ❑ Submarine Hoses.

Challenge obtaining Industry Data

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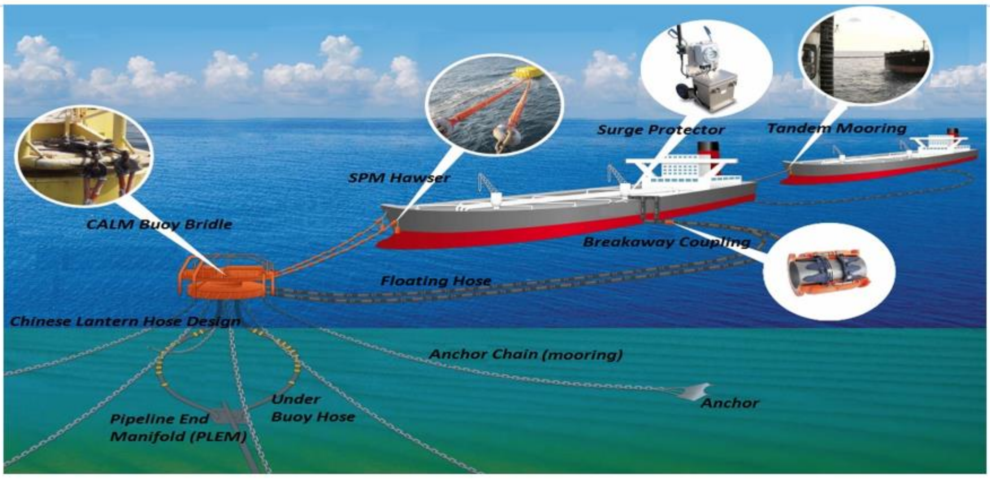
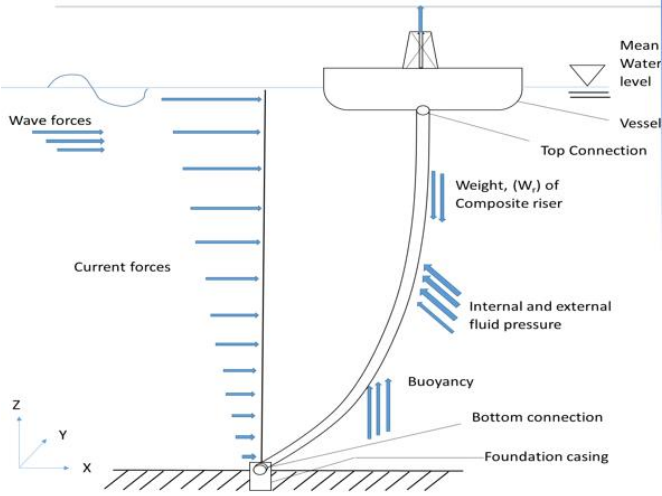
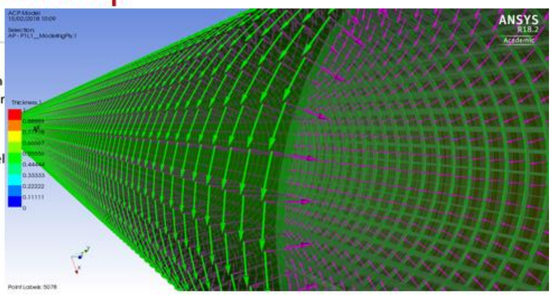
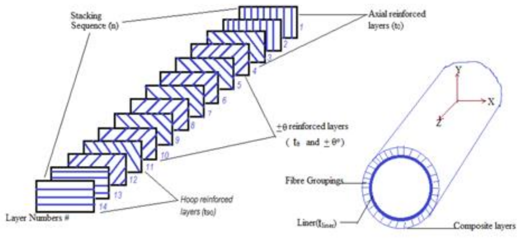
Industry Application: CALM Buoy-Chinese Lantern (courtesy SBM)



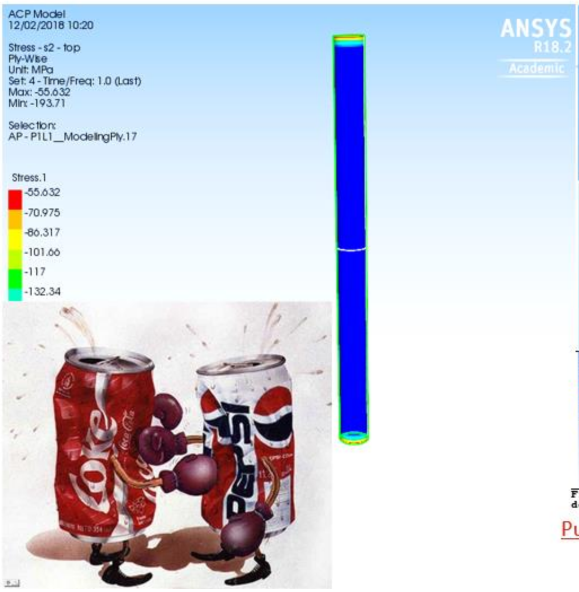
Loads on composite risers & Stack-up







Stress and Buckling of Composite Riser



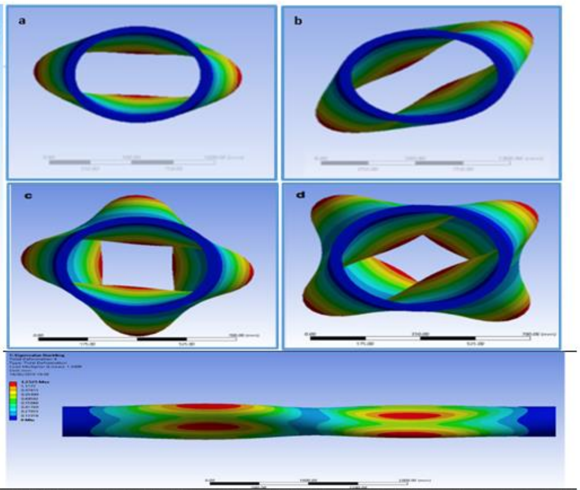


Figure 5 Eigenvalue Buckling Analysis showing end view of modes 1-4 deformation (a-d) and the plan view of mode 4 deformation (e), in ANSYS 19.0, relatively scaled for visualization

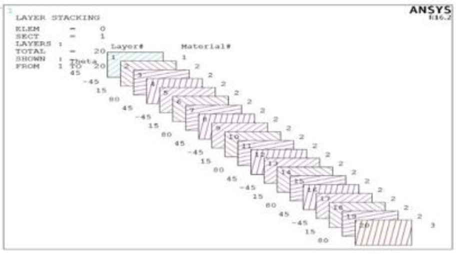
Published: https://doi.org/10.1016/j.compstruct.2018.11.057

For Composite Riser Design

- Metal Composite Interface (MCI)
- End-Fitting,
- Liners,
- Resins
- Composite Riser Pipe

Riser Load Categories (DNV, 2010)

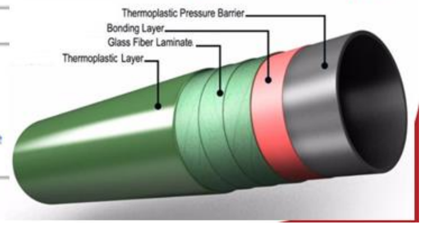
- Functional loads,
- Environmental loads,
- Accidental loads, and
- Pressure loads.



Design load cases for composite riser

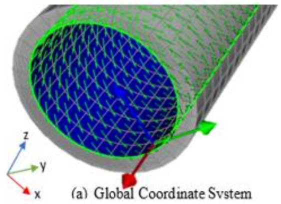
Load Case	Name	Description
Load Case 1	Burst Case with end load effect	An internal pressure of 155.25 MPa is applied
Load Case 2	Collapse Case	An external pressure of 60 MPa is applied
Load Case 3	Pure Tension Case	The load factor of 2.25 with maximum tension
Load Case 4	Internal Pressure and Tension Case	An internal pressure of 155.25 MPa is applied on the tension
Load Case 5	External Pressure and Tension Case	The load factor of 2.25 is applied on 19.5 MPa external pressure
Load Case 6	Buckling Case	An external pressure of 60 MPa is applied

Parametric Composite Riser lay-up

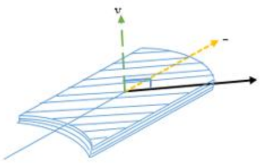


Parameters for composite riser

Parameter	Value
Length of Riser (m)	3
Outer Diameter (m)	0.3048
Surface Area (m^2)	7.6605
Number of Layers	18
Water Depth (m)	2000



(a) Global Coordinate System



(b) Material Coordinate System

Mechanical Properties of the liner

Material	Density (kg/m^3)	E_1 (GPa)	$E_2 = E_3$ (GPa)	$G_{12} = G_{13}$ (GPa)	G_{23} (GPa)	σ_1^T (GPa)	σ_1^C (GPa)	σ_2^T (GPa)	σ_2^C (GPa)	τ_{12} (GPa)	$\upsilon_{12} = \upsilon_{13}$	υ_{23}
AS4/PEEK (APC2)	1561	131	8.7	5.0	2.78	1648	864	62.4	156.8	125.6	0.28	0.48
IM7/PEEK (APC2)	1320	172	8.3	5.5	2.8	2900	1300	48.3	152	68	0.27	0.48
P75/PEEK (APC2)	1773	280	6.7	3.43	1.87	668	364	24.8	136	68	0.30	0.69
AS4/Epoxy (938)	1530	135.4	9.37	4.96	3.2	1732	1256	49.4	167.2	71.2	0.32	0.46
P75/Epoxy (938)	1776	310	6.6	4.1	2.12	720	328	22.4	55.2	176	0.29	0.70
Glass fibre/Epoxy (S-2)	2464	87.93	16.0	9.0	2.81	4890	1586	55.0	148	70	0.26	0.28
Carbon fibre/Epoxy (T700)	1580	230	20.9	27.6	2.7	4900	1470	69	146	98	0.2	0.27

Local design cases

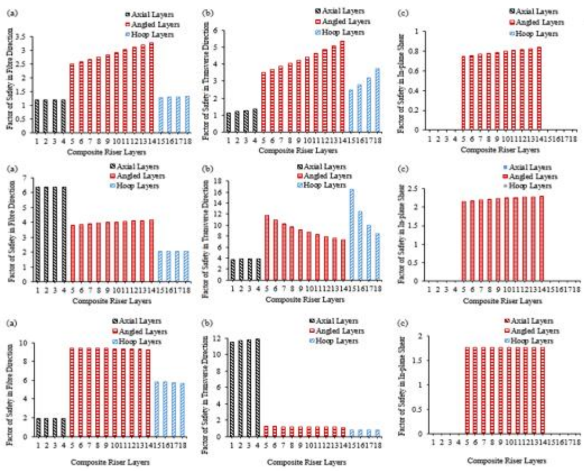


Figure 4 Factor of Safety profiles for the layers of the composite riser using AS4/Epoxy and titanium liner with $[0_4,(\pm 53.5)_5,90_4]$ configuration under: i) burst load case in (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; ii) collapse load case in (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; and iii) pure tension load case in (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction.

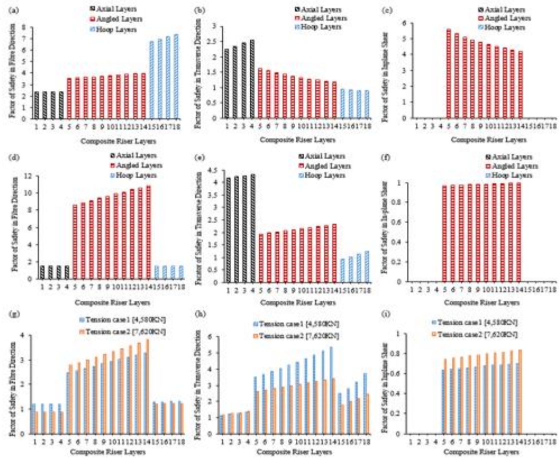
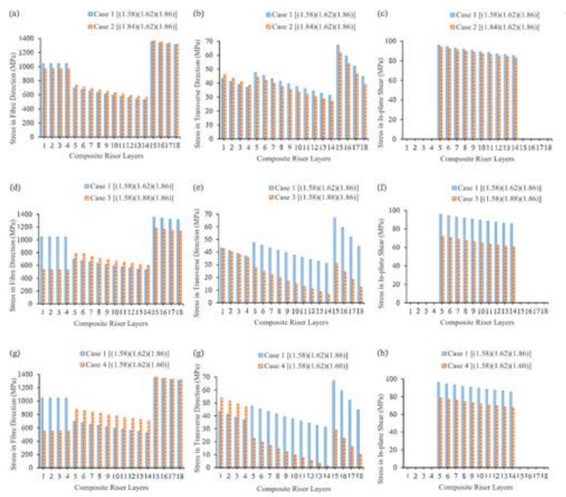
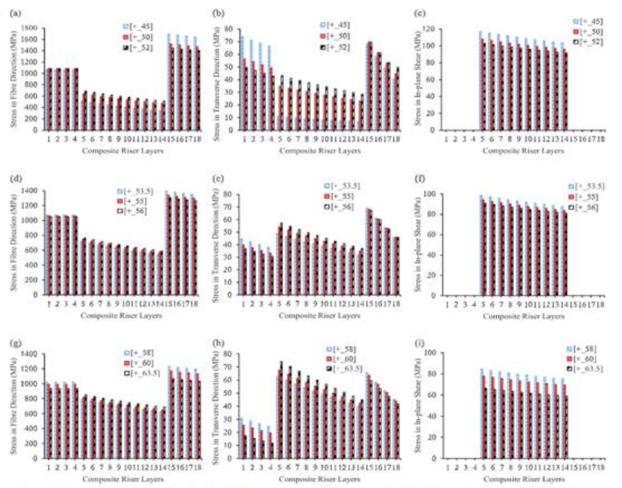


Figure 5 Factor of Safety profiles for the layers of the composite riser configured with AS4/Epoxy and $[0_4,(\pm 53.5)_5,90_4]$ configuration under: i) tension with internal pressure load case using titanium liner in (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; ii) tension with external pressure load case using titanium liner in (d) Fibre Direction, (e) Transverse Direction, (f) In-plane Shear Direction; and iii) burst load case with end load effect using aluminium liner to investigate the effect of tension force during installation in (g) Fibre Direction, (h) Transverse Direction, (i) In-plane Shear Direction.

Parametric studies-thickness & fibre angles



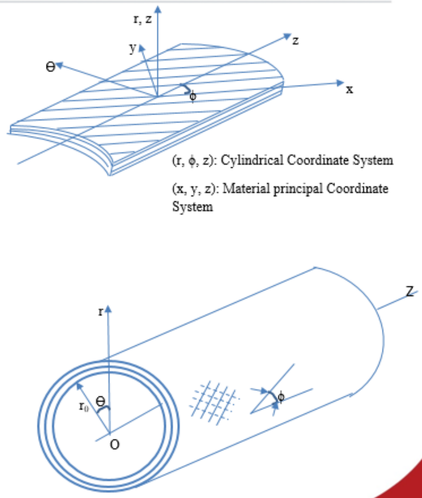
AS4/Epoxy and Aluminium liner with $[0_4,(\pm 53.5)_5,90_4]$ configuration of composite riser on the effect of: i) the axial layer thickness in the (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; ii) the off-axis layer thickness in the (d) Fibre Direction, (e) Transverse Direction, (f) In-plane Shear Direction; iii) and the hoop layer thickness in the (g) Fibre Direction, (h) Transverse Direction, and (i) In-plane Shear Direction.



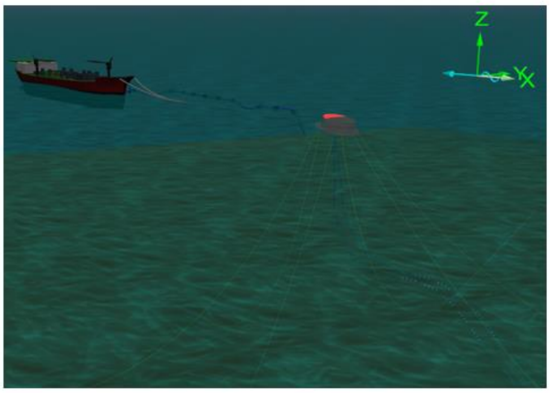
Stress profiles for composite riser configured using AS4/Epoxy and Aluminium liner to investigate off-axis layer orientation on: i) $[0_4,(\pm 45)_5,90_4]$, $[0_4,(\pm 50)_5,90_4]$, $[0_4,(\pm 52)_5,90_4]$ in: (a) Fibre Direction, (b) Transverse Direction, (c) In-plane Shear Direction; ii) $[0_4,(\pm 53.5)_5,90_4]$, $[0_4,(\pm 55)_5,90_4]$, $[0_4,(\pm 56)_5,90_4]$ in: (d) Fibre Direction, (e) Transverse Direction, (f) In-plane Shear Direction; and iii) $[0_4,(\pm 58)_5,90_4]$, $[0_4,(\pm 60)_5,90_4]$, $[0_4,(\pm 63.5)_5,90_4]$ in: (g) Fibre Direction, (h) Transverse Direction, and (i) In-plane Shear Direction.

Optimisation Summary

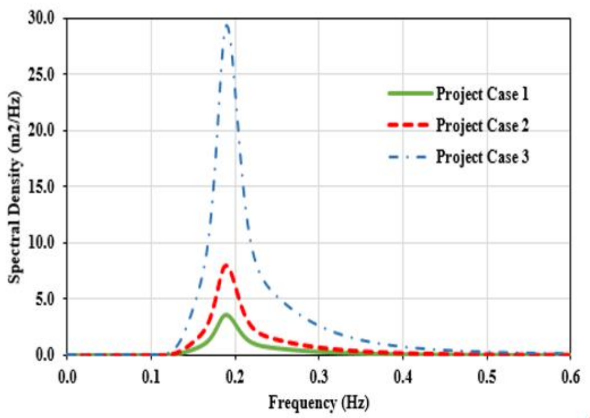
Optimisation	Impact on the Design
Decrease axial laminae orientation	There is noticeable reduction in the tensile stresses in fibre direction under the pure tension load case. The axial fibres have an increase in the stresses in the in-plane shear component.
Decrease hoop laminae orientation	There is noticeable reduction in the tensile stresses in fibre direction. The hoop fibres have an increase in the stresses in the in-plane shear component.
Increase off-axis laminae orientation	There is redistribution of stress. The equivalent stress in the liner decreases. Maximum stress in the fibre direction in both the hoop and axial layers slightly change in non-critical off-axis laminae.
Increase axial layer thickness	Reduction in the equivalent stress in the liner. Reduction in the maximum stress in the fibre direction of the hoop layers. Maximum stress in the transverse direction of the axial layers decrease.
Increase hoop layer thickness	Reduction in the equivalent stress in the liner. Maximum stress in the fibre direction of the hoop layers decrease. Maximum stress in the transverse direction of the axial layers decrease.
Iteratively decrease liner and hoop laminae thickness	The equivalent stress in the liner increases to a value slightly below the allowable stress of the aluminium liner. There is an increase in the maximum stresses in both the fibre direction and transverse direction to within 97% and 99% of the corresponding allowable stresses, respectively.



JONSWAP Spectrum for the 3 Environmental Project Cases

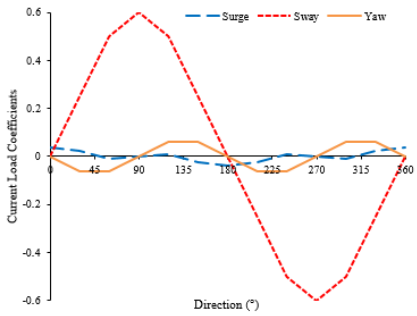


Coupled analysis of offloading system with hoses

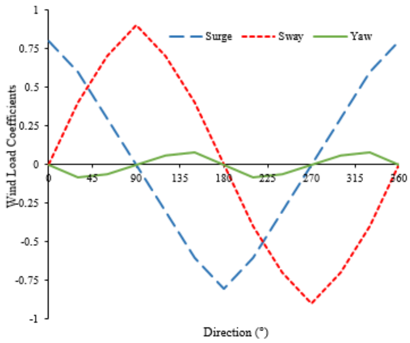


JONSWAP Wave Spectrum

Current and Wind



Current Load Coefficient for CALM buoy

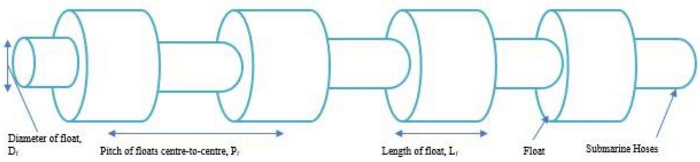


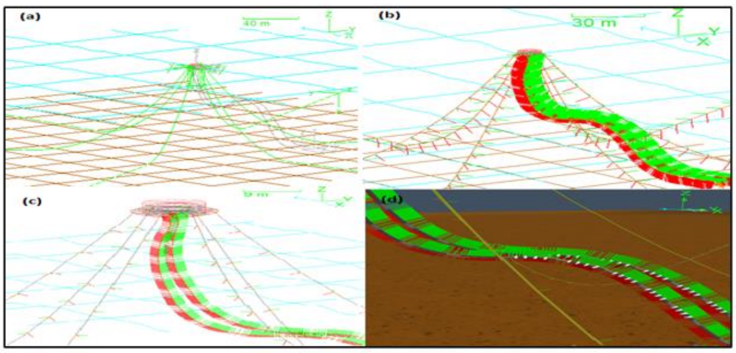
Wind Load Coefficient for CALM buoy

Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy, Ocean Engineering,

Volume 171, 2019, Pages 429-442, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2018.11.010.

Typical floats attached to submarine hoses





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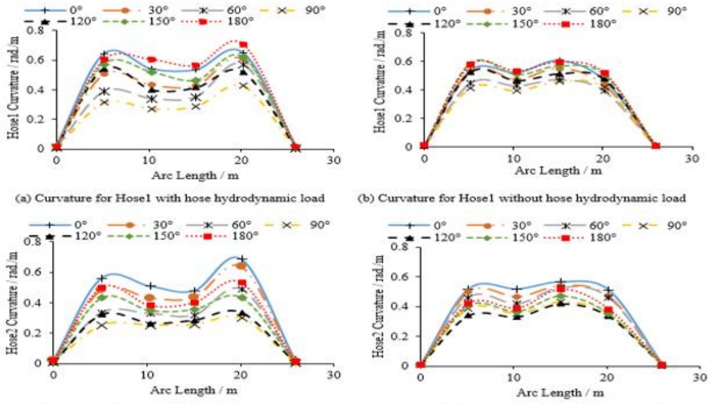
Effect of RAOs on curvature



(a) Curvature for Hose1 with hose hydrodynamic load (b) Curvature for Hose1 without hose hydrodynamic load

(c) Curvature for Hose2 with hose hydrodynamic load (d) Curvature for Hose2 without hose hydrodynamic load

Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy, Ocean Engineering,

Volume 171, 2019, Pages 429-442, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2018.11.010.

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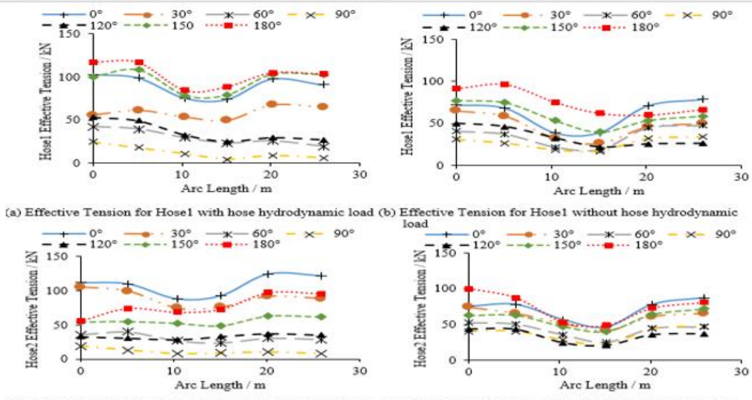
Effect of RAOs on effective tensions



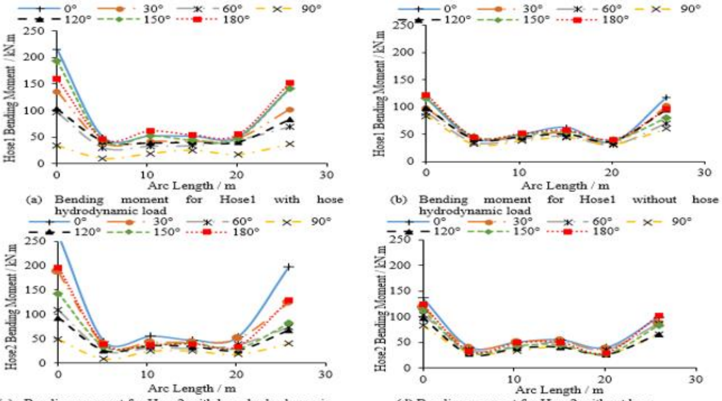
(a) Effective Tension for Hose1 with hose hydrodynamic load (b) Effective Tension for Hose1 without hose hydrodynamic load

(c) Effective Tension for Hose2 with hose hydrodynamic load (d) Effective Tension for Hose2 without hose hydrodynamic load

Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy, Ocean Engineering,

Volume 171, 2019, Pages 429-442, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2018.11.010.

Effect of RAOs on bending moments



(a) Bending moment for Hose1 with hose hydrodynamic load

(b) Bending moment for Hose1 without hose hydrodynamic load

(c) Bending moment for Hose2 with hose hydrodynamic load

(d) Bending moment for Hose2 without hose hydrodynamic load

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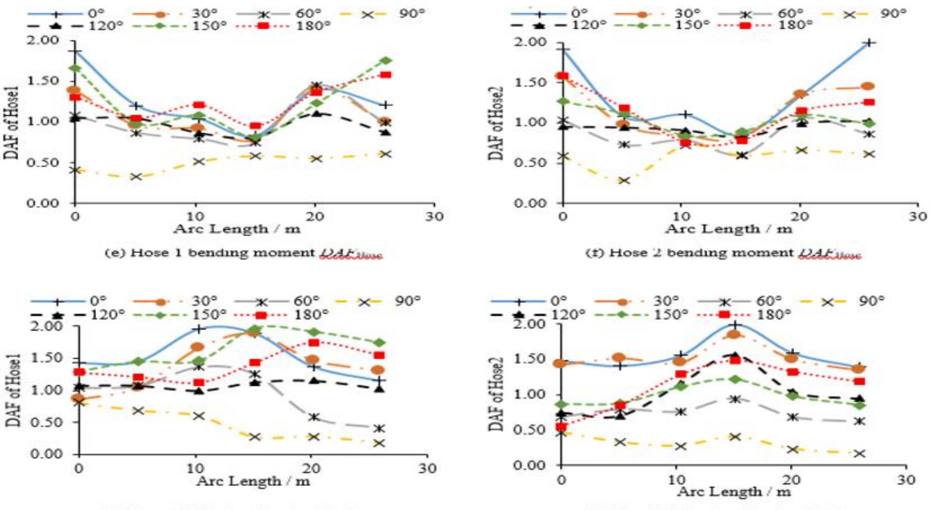
Volume 171, 2019, Pages 429-442, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2018.11.010.

DAF of hose bending moment & eff. tension



(e) Hose 1 bending moment DAF_{Hose}

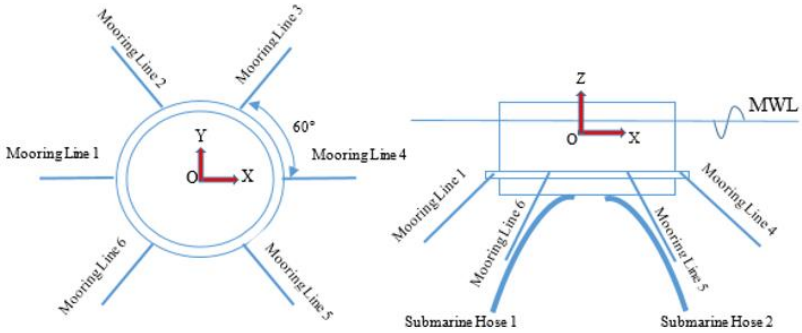
(f) Hose 2 bending moment DAF_{Hose}

(e) Hose 1 Effective Tension DAF_{Hose}

(f) Hose 2 Effective Tension DAF_{Hose}

Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy, Ocean Engineering, Vol. 171, 2019, Pages 429-442, https://doi.org/10.1016/j.oceaneng.2018.11.010

Local Coordinate System for Buoy in Chinese-lantern configuration on flat seabed with Mooring Lines in (a) buoy top view (b) buoy plan view



(a) Buoy Top View (b) Buoy Plan View

Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy, Ocean Engineering,

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Experimental work on submarine hose using CALM buoy model on Lancaster University Wave Tank

(images taken using Underwater camera, from different views)

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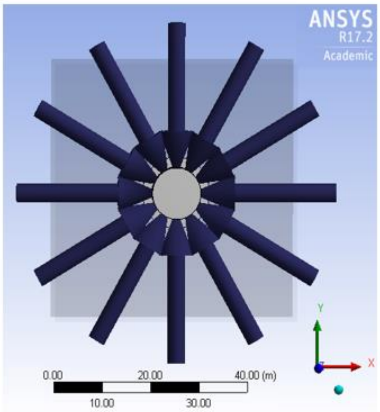
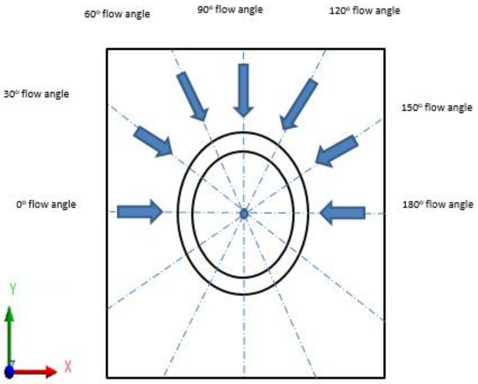
Wave Angles & Flow Angles





Not drawn to scale

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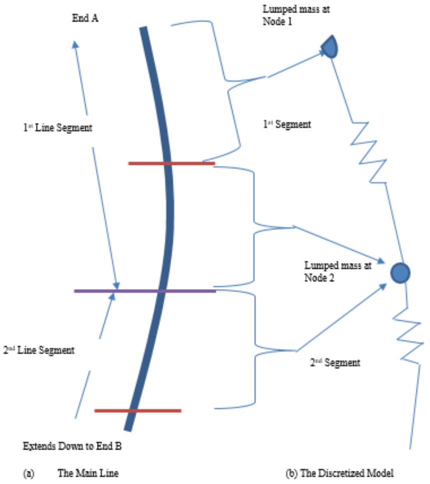
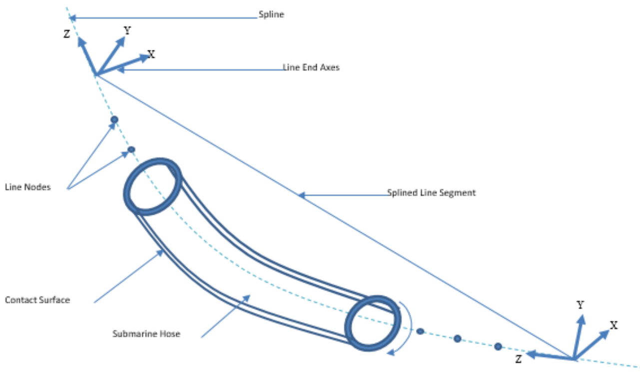
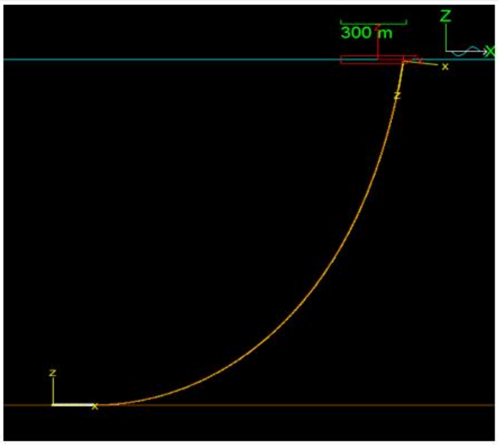
Orcaflex Line Model (Reproduced, courtesy: Orcina, 2014)

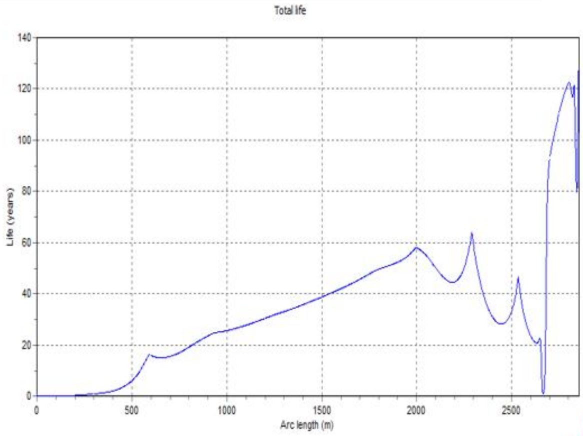




Spline Segment

Fatigue Analysis of Flexible Riser System





Wave Forces on Offshore Structures

- Offshore structures are subject to various loads. These loads include the wave forces, currents forces, tension forces, etc.
- The behaviour of an offshore structure is subject to diffraction forces. This leads to hydrodynamics study. The principle of this originates from Morison's Equation.
- Waves can either be Regular or Irregular. An example of Regular waves is Dean Stream Wave; For Irregular wave is JONSWAP.
- Different wave theories can be applied, depending on the ocean condition. They have different properties too.
- An example is the Linear Wave Theory. This is used in Froude-Kyrov forces, which assumes that pressure field is undisturbed and is applied for diffraction analysis of offshore structures.

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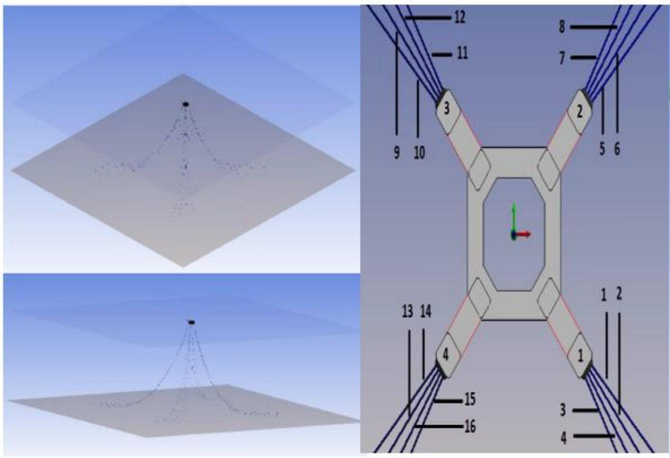
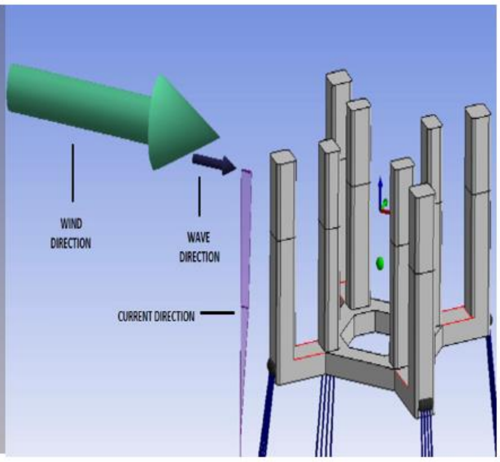
Mooring Design of PC SemiSub



Hydrodynamic Domain of arrangement of Moorings



Hydrodynamic Model - Wind, Wave & Current

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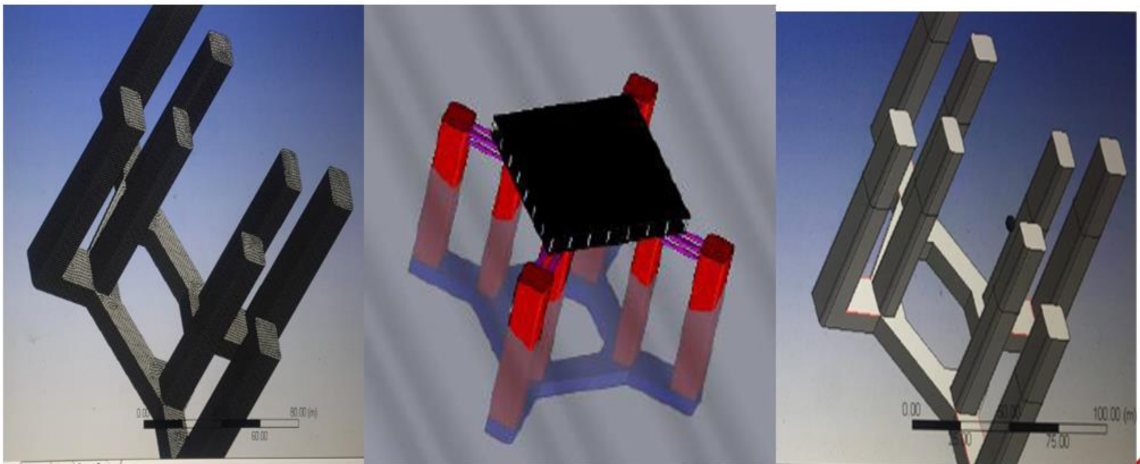
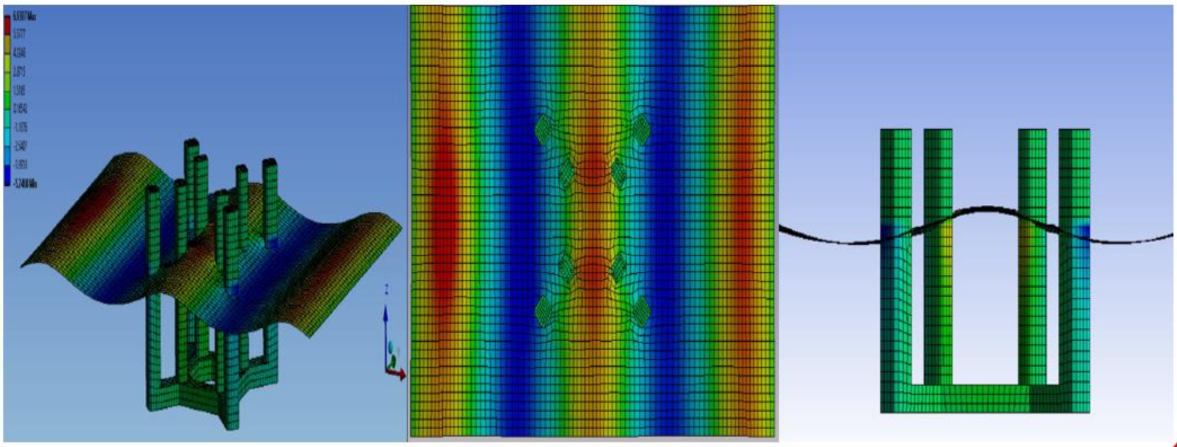
Hydrodynamic Model & Kinematics of Paired Column Semisub

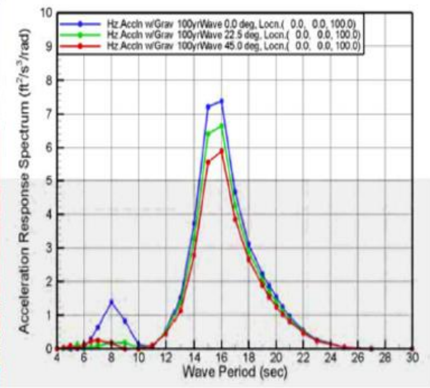


Pressures & Motions Profile of PC SemiSub

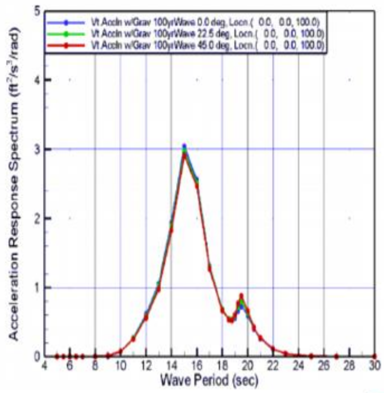


Results from Experiment on Wave Tank

Validation Results



Horizontal Acceleration Response



Vertical Acceleration Response

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Brief on composite risers project

- Current trend in oil and gas led to more technologies
- Need for lighter materials led to the need for composites
- Composites have high strength and light weight properties that can be harnessed in the offshore industry;
- Composite materials can be modeled using softwares and codes -ANSYS ACP;
- Composite Materials have advantages which could be utilised in the offshore riser application to improve riser technology;
- Research on Composite Risers have been on for about 27 years;
- Companies like Airborne and Magma have successful applications of composite pipes and composite risers;
- More collaboration needed- industry, academia, stakeholders

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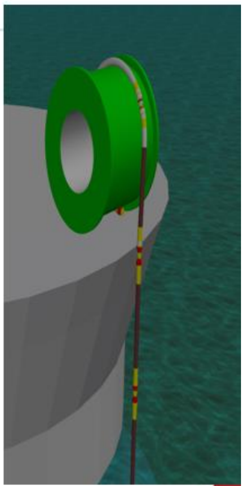
KeyPoints of Composite Risers

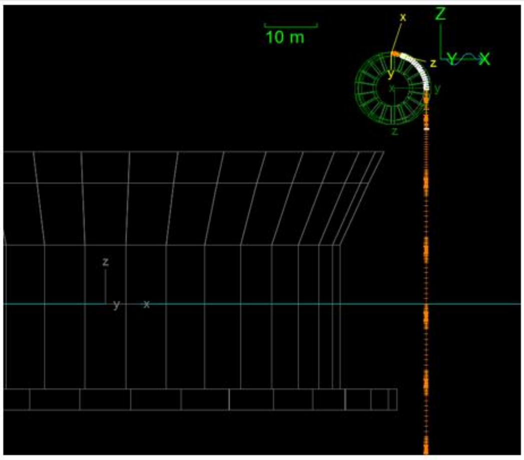
- First time composite risers were successfully deployed was in 1995 on Heidrun Platform;
- Composites have high strength and light weight properties that can be harnessed in the offshore industry;
- Composite materials can be modeled using softwares and codes -ANSYS ACP;
- Composite Materials offer a range of benefits which could be utilised in the offshore riser application to improve riser technology;
- Research on Composite Risers have been on for about 27 years;
- Companies like Airborne and Magma have successful applications of composite pipes and composite risers;

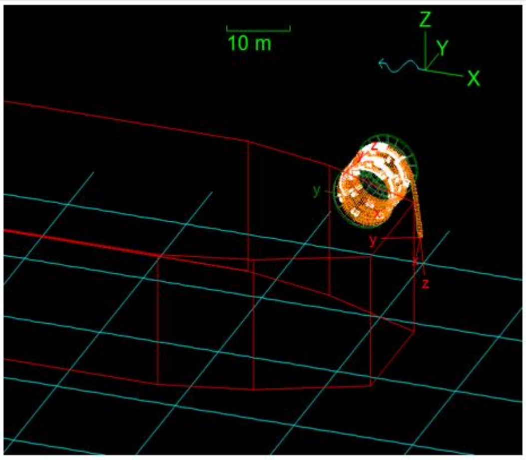
Procedure

- Stage 1: A reeling analysis will be developed in OrcaFlex to determine the directional connection forces and bending moments (maximums) on each riser section.
- Stage 2: CAD model of the riser in its curved shaped taken as drum curvature; i.e., the riser is assumed to be completely supported by the drum. CAD model should identify fitting and rubber interface, as well as different layers of the composite riser.
- Stage 3: FEA model using Ansys Structural. (Material properties of each layer will be provided, including the geometric parameters o each riser section

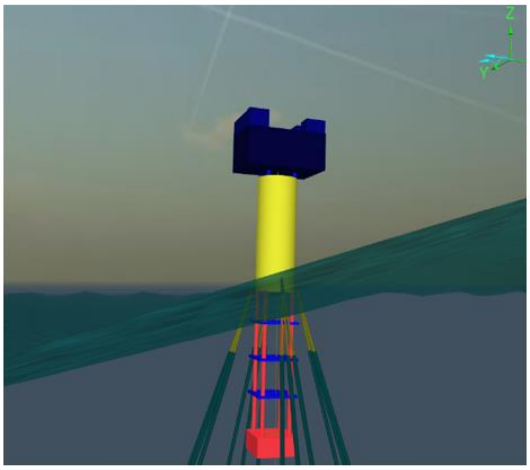


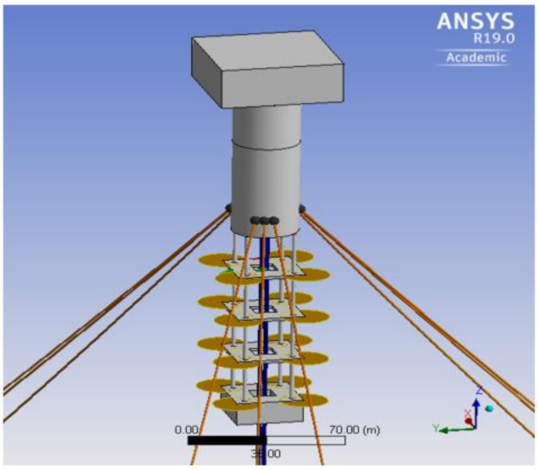
Constraints on Reel Hose



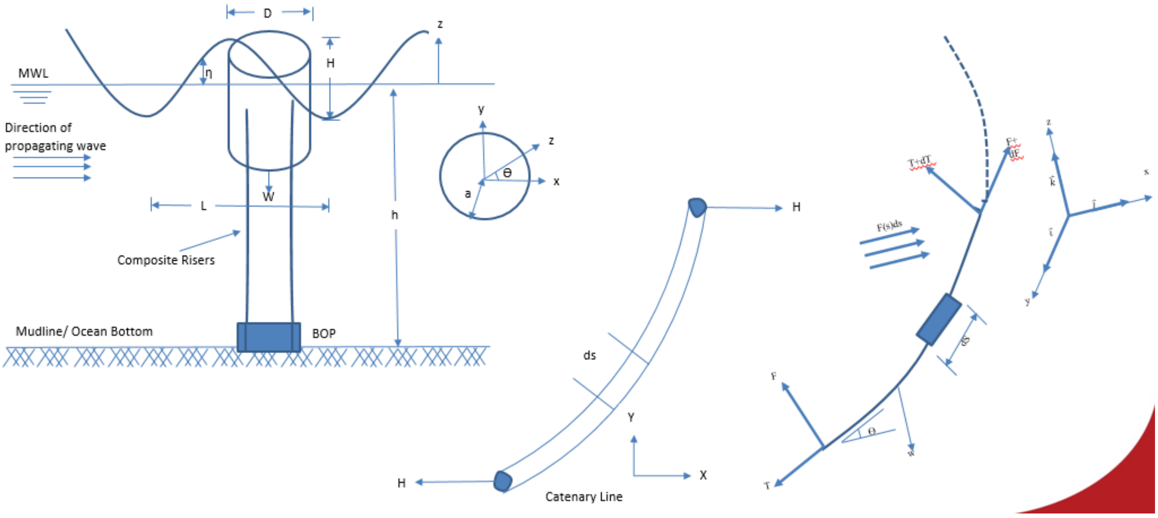


Global Design on SPAR in Orcaflex





Sketch of risers on SPAR design



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Publications

1. Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy; Ocean Engineering, Volume 171, 1 January 2019, Pages 429-442; Authors: Chiemela Victor Amaechi, Facheng Wang, Xiaonan Hou, Jianqiao Ye
https://doi.org/10.1016/j.oceaneng.2018.11.010

2. Composite risers for deep waters using a numerical modelling approach; Composite Structures, Volume 210, 15 February 2019, Pages 486-499;
Authors: Chiemela Victor Amaechi, Nathaniel Gillett, Agbomerie Charles Odijie, Xiaonan Hou, Jianqiao Ye https://doi.org/10.1016/j.compstruct.2018.11.057

3. Microscale intrinsic properties of hybrid unidirectional/woven composite laminates: Part I experimental tests; Composite Structures, Volume 262, 15 April 2021, 113369, Authors: Junjie Ye, Heng Cai, Lu Liu, Zhi Zhai, Chiemela Victor Amaechi, Yongkun Wang, Lei Wan Dongmin Yang, Xuefeng Chen, Jianqiao Ye https://doi.org/10.1016/j.compstruct.2020.113369

4. Sensitivity Studies on Offshore Submarine Hoses on CALM Buoy with Comparisons for Chinese-Lantern and Lazy-S Configuration: Paper OMAE2019-96755, Authors: Amaechi, C. V., Wang, F., Hou, X. & Ye, J., 10/06/2019.38th International Conference on Ocean, Offshore and Arctic Engineering, ASME OMAE, Glasgow, Scotland, UK

5. Economic Aspects of Fiber Reinforced Polymer Composite Recycling; Encyclopedia of Renewable and Sustainable Materials. Choudhury, I. & Hashmi, S. (eds.). Elsevier, Vol. 1. p. 377-397 21 p., Authors: Amaechi, C. V., Odijie, A. C., Orok, E. O. & Ye, J., 20/01/2020.

6. Recycling of Renewable Composite Materials in the Offshore Industry; Reference Module in Materials Science and Materials Engineering. Elsevier
Authors: Amaechi, C. V., Agbomerie, C. O., Sotayo, A., Wang, F., Hou, X. & Ye, J., 1/09/2019,

7. Local and Global Design of Composite Risers on Truss SPAR Platform in Deep waters. MECHCOMP2019 5th International Conference on Mechanics of Composites - Instituto Superior Técnico, Lisbon, Portugal, Lisbon, PortugalDuration: 1/07/2019 → 4/07/2019
Authors: Amaechi, C. V., Ye, J., Hou, X., Gillett, N., Odijie, A. C. & Wang, F., 3/07/2019.

8. A numerical modeling approach of composite risers for deep waters; ICCS20 20th International Conference on Composite Structures. Ferreira, A. J. M., Larbi, W., Deu, J-F., Tornabene, F. & Fantuzzi, N. (eds.). Societa Editrice Esculapio, p. 262-263 2 p. (Structural and Computational Mechanics Book Series)., Authors: Amaechi, Chiemela Victor & Ye, Jianqiao., 8/09/2017

9. Liner wrinkling and mechanical behaviour offshore composite bonded hoses (OBCH) using local design pressure for burst and collapse. Submitted to Composites Part A Journal. 2021

10. Finite element model on the global and local design of offshore composite bonded hoses for operational reeling conditions. Submitted to Engineering Structures Journal. 2021

11. Parametric investigation on marine drilling riser of a Paired Column Semisubmersible considering tensioner stroke analysis, recoil analysis and disconnect in deep water waves. Submitted to Renewable and Sustainable Energy Reviews. 2021

12. Experimental and numerical investigation on the dynamic behaviour of submarine hoses attached to CALM buoy in Lazy-S configuration. Submitted to Renewable Energy. 2021

13. Experimental and numerical studies of CALM buoy hydrodynamic responses on the effect of buoy geometries and buoy skirts under wave loadings. Submitted to Ocean Engineering. 2021

14. A novel coupling model on CALM buoy submarine hoses with sensitivity studies and comparisons for Lazy-S and Chinese-lantern configurations under irregular waves. Submitted to Renewable and Sustainable Energy Reviews. 2021

15. Tailored local design of deep water composite risers under burst, collapse, tension and combined loadings with parametric investigations. Submitted to Composites Part B. 2021

16. High amplitude flow analysis of marine risers array system and column array of Paired Column Semisubmersible by varying wave angles based on fluid-structure interaction. Submitted to Renewable Energy Journal. 2021

17. A novel tensioner model applied on global response of marine riser recoil and disconnect. Submitted to Ocean Engineering Journal. 2021

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Thank You